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WATER BUDGET FOR SRP BURIAL GROUND AREA

INTRODUCTION AND SUMMARY

Radionuclide migration from the SRP burial ground[1] for solid low-level waste has been studied extensively.[2] Most of the buried radionuclides are fixed on the soil and show negligible movement. The major exception is tritium, which when leached from the waste by percolating rainfall, forms tritiated water and moves with the groundwater.[3] The presence of tritium has been useful in tracing groundwater flow paths to outcrop. A subsurface tritium plume moving from the southwest corner of the burial ground toward an outcrop near Four Mile Creek has been defined.[4] Groundwater movement is so slow that much of the tritium decays before reaching the outcrop.

The burial ground tritium plume defined to date is virtually all in the uppermost sediment layer, the Barnwell Formation. The purpose of the study reported in this memorandum was to investigate the hypothesis that deeper flow paths, capable of carrying substantial amounts of tritium, may exist in the vicinity of the burial ground. The most probable location of deeper flow paths is

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in the McBean Formation, separated from the Barnwell by a "tan clay" layer.

As a first step in seeking deeper flow paths, a water budget was constructed for the burial ground site. The water budget, a materials balance used by hydrologists, is expressed in annual area inches of rainfall. Thus, the total inches of annual rainfall are separated into various consequences of the water, which include evapotranspiration, run-off, and groundwater recharge.

Components of the water budget for the burial ground area were analyzed to determine whether significant flow paths may exist below the "tan clay." Mean annual precipitation was estimated as 47 inches, with evapotranspiration, run-off, and groundwater recharge estimated as 30, 2, and 15 inches, respectively. These estimates, when combined with groundwater discharge data, suggest that 5 inches of the groundwater recharge flow above the "tan clay" and that 10 inches flow below the "tan clay." Therefore, two-thirds of the groundwater recharge appears to follow flow paths that are deeper than those previously found.

BACKGROUND

The low-level waste burial ground is located between the F and H Separations Areas, well within the Savannah River Plant site. Figure 1 shows water table contours in meters above sea level. The water table is about 12 meters below the land surface in the vicinity of the burial ground. Most of the burial ground is just to the south of the water table divide, with the water table sloping gently westward and southward toward Four Mile Creek. Upper Three Runs Creek, in a more deeply incised valley to the north and west, drains a small portion of the burial ground.

A tritium plume in the shallow groundwater (in the Barnwell Formation) has moved slowly, a few tens of feet yearly, from the burial ground toward Four Mile Creek and its F-Effluent tributary, as shown in Figure 2. This flow path is described by Fenimore[4] and displayed by WDT in a three-dimensional model. The tritium plume is mostly in very shallow groundwater above a less permeable "tan clay" which separates the Barnwell Formation from the McBean Formation below it.

Figure 3 illustrates a simplified water balance. The input is rainfall precipitation (P). Losses include surface and subsurface run-off (SR), which rapidly moves to drainage ditches at the site and to streams. Evaporation from the surface and transpiration through vegetation return to the atmosphere as evapotranspiration (ET). The remaining water percolates downward to recharge (R_x) the groundwater at the water table. Storage is reflected in the rising and lowering of the water table. Groundwater migrates slowly toward places of lower hydraulic potential, discharging (D_x) as springs, seeps, or the base flow of streams. Over sufficiently long periods, often a water year, storage can be neglected, so that discharge can be assumed to equal recharge.

RESULTS

The following estimates, expressed for the average yearly rainfall, are the results of the study reported in this memorandum.

Mean Annual Water Budget

Precipitation	47 inches
Evapotranspiration	30 inches
Run-off	2 inches
Groundwater Recharge	15 inches

Groundwater Discharges

Above the "tan clay"	5 inches
Below the "tan clay"	10 inches

WATER BUDGET COMPONENTS

Precipitation

An annual average of 47 inches of precipitation, with a standard deviation of just less than 10 inches, is representative of the Coastal Plain in this region. Table 1 gives precipitation data taken at or near the burial ground over the 20-year period 1963-1982. Average rainfall is well distributed throughout the year with the least precipitation in the fall months.

Evapotranspiration

Losses to the atmosphere from the surface and through vegetation were estimated the following ways: (1) water balance of stream basins; (2) climatic estimates; (3) water balance of lysimeters.

To estimate evapotranspiration from the water balance of three nearby stream basins, streamflow records were expressed as water yield in inches and then were subtracted from mean annual rainfall. By this method the estimate of evapotranspiration is 30 inches, as shown in Table 2.

Climatic estimates of evapotranspiration were made by two methods. In the first method monthly temperature and rainfall values were combined with some site variables to provide water balance estimates by the Thornthwaite[5] procedure. As shown in Table 3, this method gives an estimate of 36 inches. In the second method evaporation pan data from the South Carolina Agriculture Experiment Station as reported in Cahill[6] were multiplied by ratios developed at U. S. Department of Agriculture research watersheds at Tifton, Georgia.[7] By this method evapotranspiration estimates averaged 33 inches, as shown in Table 4.

Wasteform lysimeter research data[8] also provided water budget estimates which are shown in Table 5. The actual data shown in Table 5 was derived from raw data used to produce the tables in the wasteform lysimeter research data of reference 8. As shown in Table 5, mean evapotranspiration for the three years 1980-1982 was 26.3 inches. Allowance for below-normal rainfall in that period yields an adjusted normal evapotranspiration of 30 inches.

Run-off

The run-off estimate of 2 inches is made subjectively from streamflow records, soil survey inspection, and reported observations of infrequent water in drainage ditches at the burial ground.

When a storm event occurs, run-off rapidly reaches a stream and produces the rising limb, flow peak, and recession of the hydrograph (Figure 4). The base flow contributed by groundwater may be separated into the run-off and base flow contributions by analysis of the hydrograph. However, flow separation in Four Mile Creek is difficult because of daily water releases from F and H Separations Areas.

Streamflow analysis is illustrated in Figure 5 for the cumulative frequency of flows equaled or exceeded in Rocky Creek, the Congaree River, and Four Mile Creek. Streams such as Rocky Creek with only a slight groundwater contribution to the flow tend to fluctuate greatly.[9] Streams such as the Congaree River with a considerable base flow produce a more linear and horizontal frequency curve.[9] Four Mile Creek flow for December 1981 shows some run-off by the upward tilt in the left portion of the frequency curve, but very little run-off is indicated for November 1981 or June 1982. Rainfall data at the burial ground showed 9.43 inches of rainfall in December 1981, 0.55 inches in November 1981, and 3.14 inches in June 1982.

Groundwater Recharge

Total groundwater recharge at the burial ground is estimated by the difference of evapotranspiration and run-off from the annual precipitation. The estimate is 15 inches.

Four groundwater zones in the vicinity of the burial ground are denoted schematically in Figure 6 (after Siple,[10] modified by Marine[11]). The shallowest groundwater is in the Barnwell Formation and is above a relatively less permeable "tan clay" aquitard. The hydrostatic pressure is that of the water table. The McBean Formation, below the "tan clay," is bounded below by a "green clay" aquitard. Groundwater in the McBean flows at a slightly different potential than groundwater in the Barnwell Formation above. The Congaree Formation, below the "green clay," is a deep groundwater zone, separated by another clay layer from the very deep Tuscaloosa aquifer. The Tuscaloosa extends far below sea level. The water pressure is lower in the Congaree zone than in the Tuscaloosa. This "head reversal" is associated with the higher hydraulic conductivity of the Congaree and with its hydraulic connection to the Upper Three Runs valley incised in the Congaree Formation. Upper Three Runs Creek is thought to receive part of its base flow from Congaree groundwater, whereas Four Mile Creek and most others have their bases considerably above the "green clay."

Groundwater in most of the Burial Ground area migrates slowly westward and southward toward Four Mile Creek and its F-Effluent tributary as illustrated schematically in Figure 7. The groundwater drainage basin for the shallowest (Barnwell) zone is shown in Figure 8. The base flow in F-Effluent stream above the "tan clay" was measured by Fenimore in 1980, following an erosive event in F-Effluent stream and before repair was completed. A v-notch weir was used for streamflow measurements. The water entered the stream at seeps and springs during a rain-free period in May and June 1980. Measurements were taken four times at a "tan clay" outcrop 200 feet above sea level. Groundwater discharge averaged 130 gallons per minute at this point.

This measurement, converted to other units and combined with the estimated watershed area of 0.8 square mile, gives the groundwater discharge above the "tan clay" as 0.36 cubic feet per second per square mile (CSM). Further conversion to annual rainfall inches (1 CSM = 13.57 inches per year) gives 4.9 inches. Thus, the groundwater discharge above the "tan clay" is estimated as 5 inches per year.

If total recharge is 15 inches, then these discharge measurements provide the basis for inferring that the residual recharge, 10 inches per year, lies below the "tan clay." Groundwater potentials in the McBean Formation (Figure 9) show that flow paths in the McBean should be longer, deeper, and have a more westward component than in the Barnwell. Figure 10 shows that the potential surface in the Congaree Formation (below the "green clay") would give flow paths with a west-northwest component toward Upper Three Runs Creek.

The longer flow paths would provide more time for tritium decay. This will be enhanced by the time required to pass through the considerably less permeable clays. The large, hydraulic gradient across the "green clay" implies an integrity and extent of that aquitard at the burial site. Travel time through the clay can be estimated if the thickness, effective porosity, hydraulic conductivity, and hydraulic gradient of the clay layer are known.

The continuity of the "tan clay" is less certain, as indicated by the smaller hydraulic gradient. Indeed, Cahill[6] shows that discontinuities exist in both the "tan clay" and the "green clay" at a nearby commercial burial site. Cahill treated the three groundwater zones as one at that site. Marine[11] describes the "tan clay" as "two thin clay layers separated by a sandy zone. The entire unit is about 10 to 15 feet thick and is semicontinuous over the area." Marine estimates a horizonal velocity of 12.4 feet per year in the upper McBean below the "tan clay."

CONCLUSIONS

In an average year about one-third of the rainfall recharges groundwater and almost two-thirds evaporates. When rainfall varies from its mean of 47 inches, most of the difference results in changes in the amount returned to the atmosphere.

Significant amounts of groundwater move above and below the "tan clay." Measurements indicated about 5 inches (one-third of the annual recharge) drained from the Barnwell Formation above the "tan clay." Although discharge varies with the water table in that formation, a sizable fraction of the recharge probably reaches the McBean zone.

Flow paths in groundwater below the "tan clay" would be deeper and longer than above it, thereby allowing for more tritium decay. Seeps and springs above the "tan clay" indicate the surface discharge of the shallowest groundwater. The McBean groundwater moves farther to the valleys of Four Mile Creek and Upper Three Runs Creek. Groundwater in the Congaree zone would move farther westward to Upper Three Runs Creek.

SUGGESTIONS FOR FURTHER WORK

1. The estimate of groundwater recharge to the McBean Formation should be verified experimentally with field measurements. If the postulated water budget is correct, a major tritium plume, previously undetected, may exist in the McBean Formation in the vicinity of the burial ground. Available data on tritium below the "tan clay" are sparse. New data from soil cores would help define the movement of tritium in the McBean Formation.

2. Additional modeling calculations would be useful. Root[12] has developed a computer model of groundwater that can support a tritium management model. The wasteform lysimeter data can provide a groundwater recharge input to the model responsive to rainfall variation with time.

3. Stream gage records in the Four Mile Creek and Upper Three Runs Creek drainages should be examined to determine whether drainage from the upper three zones can be separated. This would involve streamflow recession and movement of the water table at the burial site.

4. Cahill[6] identified large discontinuities in the "tan clay" and "green clay" at the nearby commercial burial site. Similar careful examination of core logs and construction of a "fence diagram" may present more information for the SRP site. Parizek and Root have compiled much of the available data.[13]

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TABLE 1

ANNUAL PRECIPITATION AT BURIAL GROUND SITE (1963-1982)*

Year	Precipitation		Year	Precipitation	
	Days	Inches		Days	Inches
1963	104	41.37	1973	106	55.13
1964	104	71.86	1974	118	47.70
1965	102	45.02	1975	132	58.44
1966	100	48.19	1976	112	52.21
1967	92	42.58	1977	111	44.70
1968	98	34.66	1978	84	36.56
1969	95	38.95	1979	130	54.15
1970	84	40.46	1980	103	38.45
1971	106	61.74	1981	105	39.72
1972	98	44.41	1982	135	51.11
			Mean, 1963-1982	106	47.32

* Recorded at F Area, 1963-1973, and at burial ground lysimeter site, 1974-1982.

TABLE 2

EVAPOTRANSPIRATION ESTIMATES
BY STREAM BASIN WATER BALANCE METHOD

Basin	Drainage Area (square miles)	Years Gaged	Water Yield (inches)	ET (inches)
Edisto River, South Fork[a]	198	27	16.6	30.7
Upper Three Runs Creek[b]	87.0	15	17.3	30.0
Marys Branch[c]	4.3	3	14.5	32.8

a. At Montmorenci. Water Resource Records of South Carolina, WY-1966.
b. At New Ellenton. Water Resource Records of South Carolina, WY-1981.
c. Near Barnwell. U. S. Geological Survey Open File Report 82-983.

TABLE 3

EVAPOTRANSPIRATION ESTIMATE
BY THORNTHWAITE METHOD*

Month	Average Temperature (°F)	ET (inches)
January	48	0.55
February	48	0.55
March	54	1.18
April	64	2.64
May	72	4.41
June	80	5.91
July	82	6.73
August	80	5.94
September	75	4.41
October	64	2.36
November	54	1.02
December	46	0.43
TOTAL		36.13

* Reference 5.

TABLE 4

EVAPOTRANSPIRATION ESTIMATE BY EVAPORATION PAN METHOD*

Month	Mean Evaporation (inches)	Pan Coefficient	ET (inches)
January	1.94	1.02	1.98
February	2.99	0.83	2.48
March	4.23	0.65	2.75
April	6.38	0.52	3.32
May	6.31	0.46	2.90
June	7.03	0.52	3.66
July	7.06	0.60	4.24
August	6.20	0.56	3.47
September	4.58	0.47	2.15
October	3.90	0.55	2.14
November	2.73	0.81	2.21
December	1.93	1.02	1.97
TOTAL	55.28		33.27

* Evaporation pan at Blackville, SC; 1974-78 monthly averages from Reference 6. Pan coefficients determined at Tifton, GA, Reference 7.

TABLE 5

EVAPOTRANSPIRATION ESTIMATE
BY LYSIMETER WATER BALANCE METHOD[a]

	Water Budget Components[b] (inches)		
	P	$SR+R_x$	ET
1980			
January - March	17.3	10.0	7.3
April - June	7.1	4.0	3.1
July - September	9.3	1.3	8.0
October - December	4.7	1.6	3.1
TOTAL	38.4	16.9	21.5
1981			
January - March	8.5	3.3	5.2
April - June	12.2	5.6	6.6
July - September	11.1	1.4	9.7
October - December	7.9	4.9	3.0
TOTAL	39.7	15.3	29.4
1982			
January - March	13.4	6.7	6.7
April - June	10.7	3.3	7.4
July - September	18.4	5.8	12.6
October - December	8.6	2.4	6.2
TOTAL	51.1	18.2	32.9
Average, 1980-1982			
January - March	13.1	6.7	6.4
April - June	10.0	4.3	5.7
July - September	12.9	2.8	10.1
October - December	7.1	3.0	4.1
TOTAL	43.1	16.8	26.3
Normalized	47.3	17.6	29.7

a. SRP wasteform lysimeters; data derived from raw data used to produce Reference 8.

b. Precipitation (P); Runoff + Groundwater Recharge ($SR + R_x$); Evapotranspiration (ET).

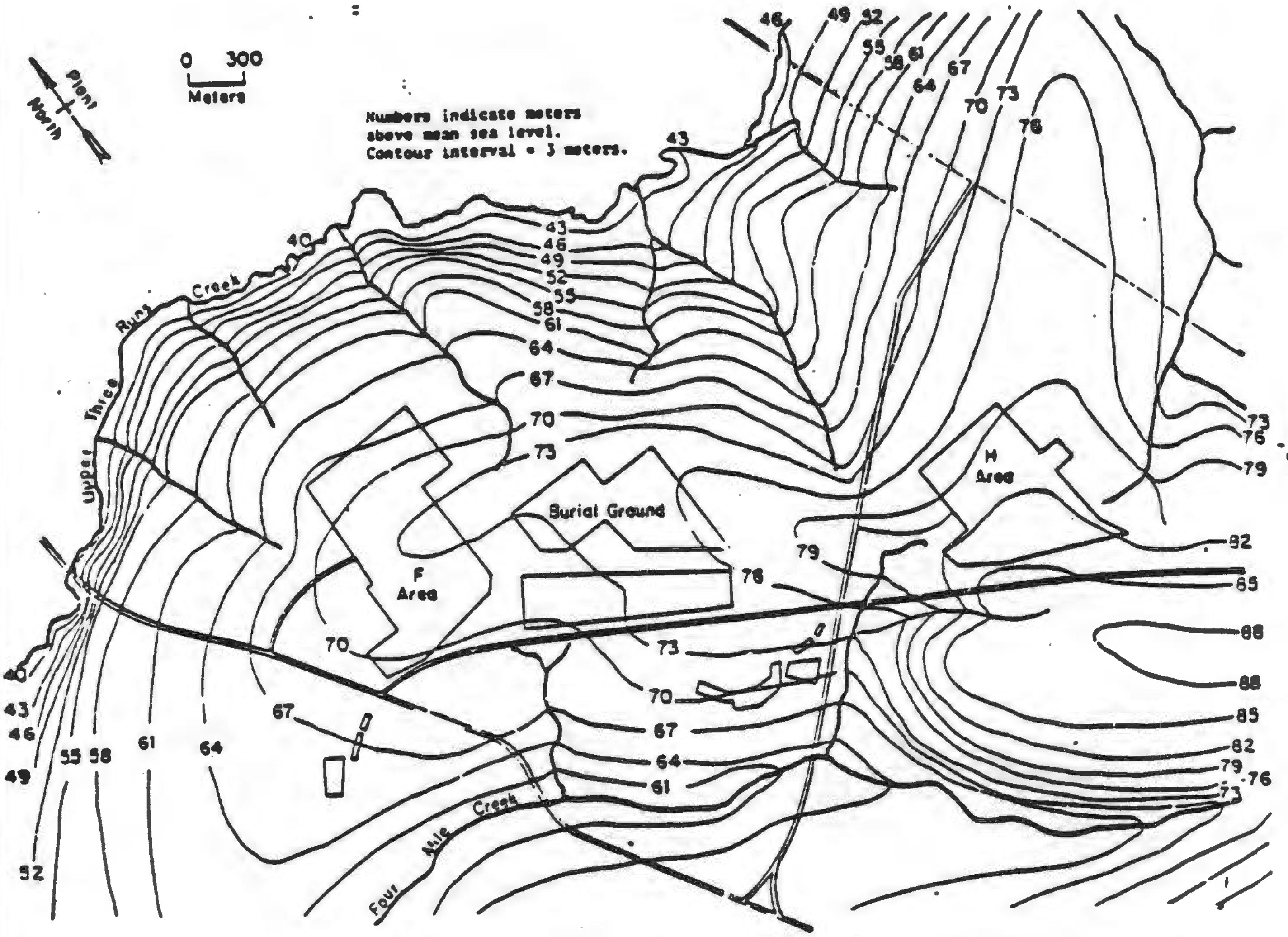


Figure 1. Average Elevation of the Water Table at SRP During 1968

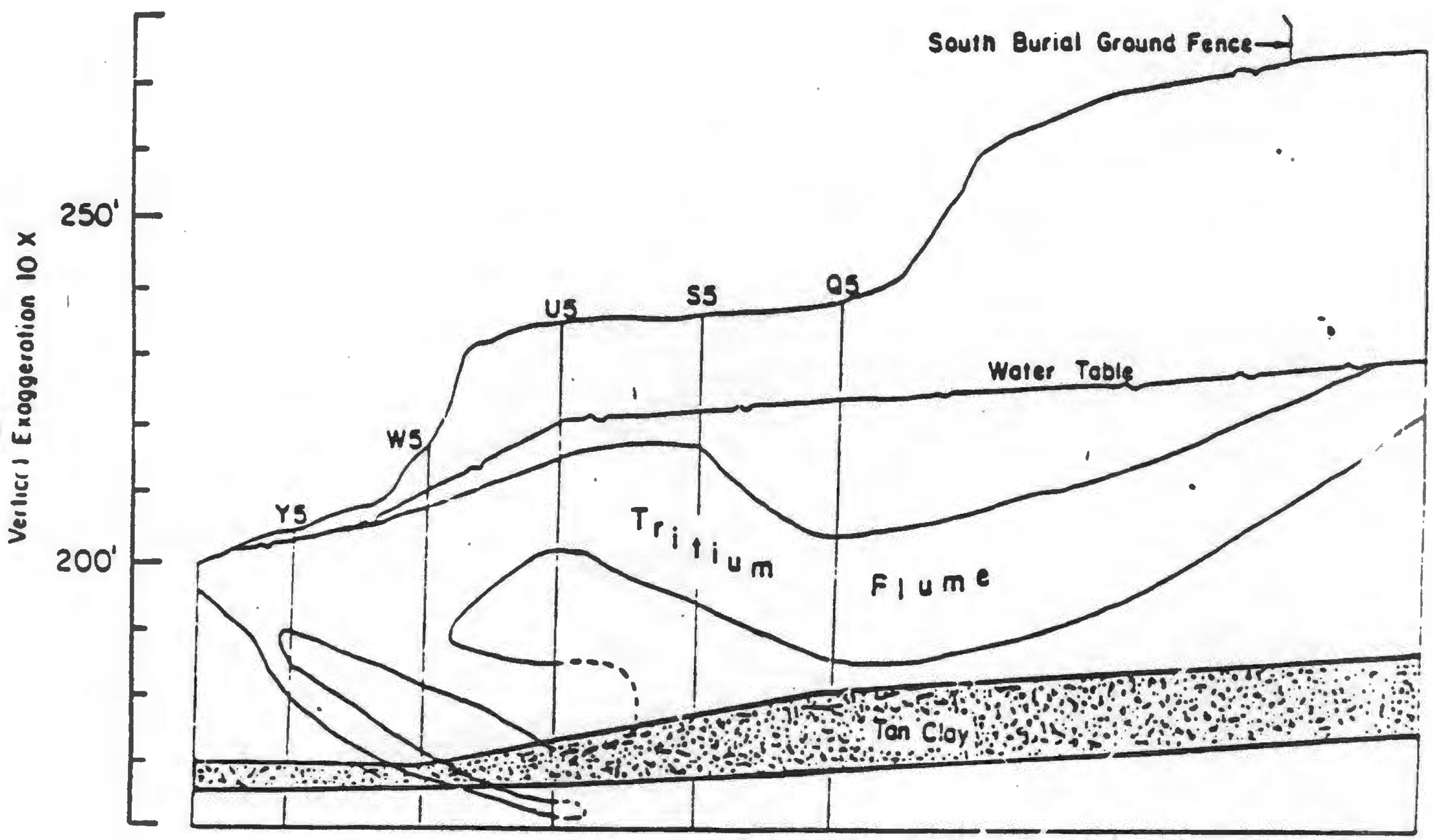
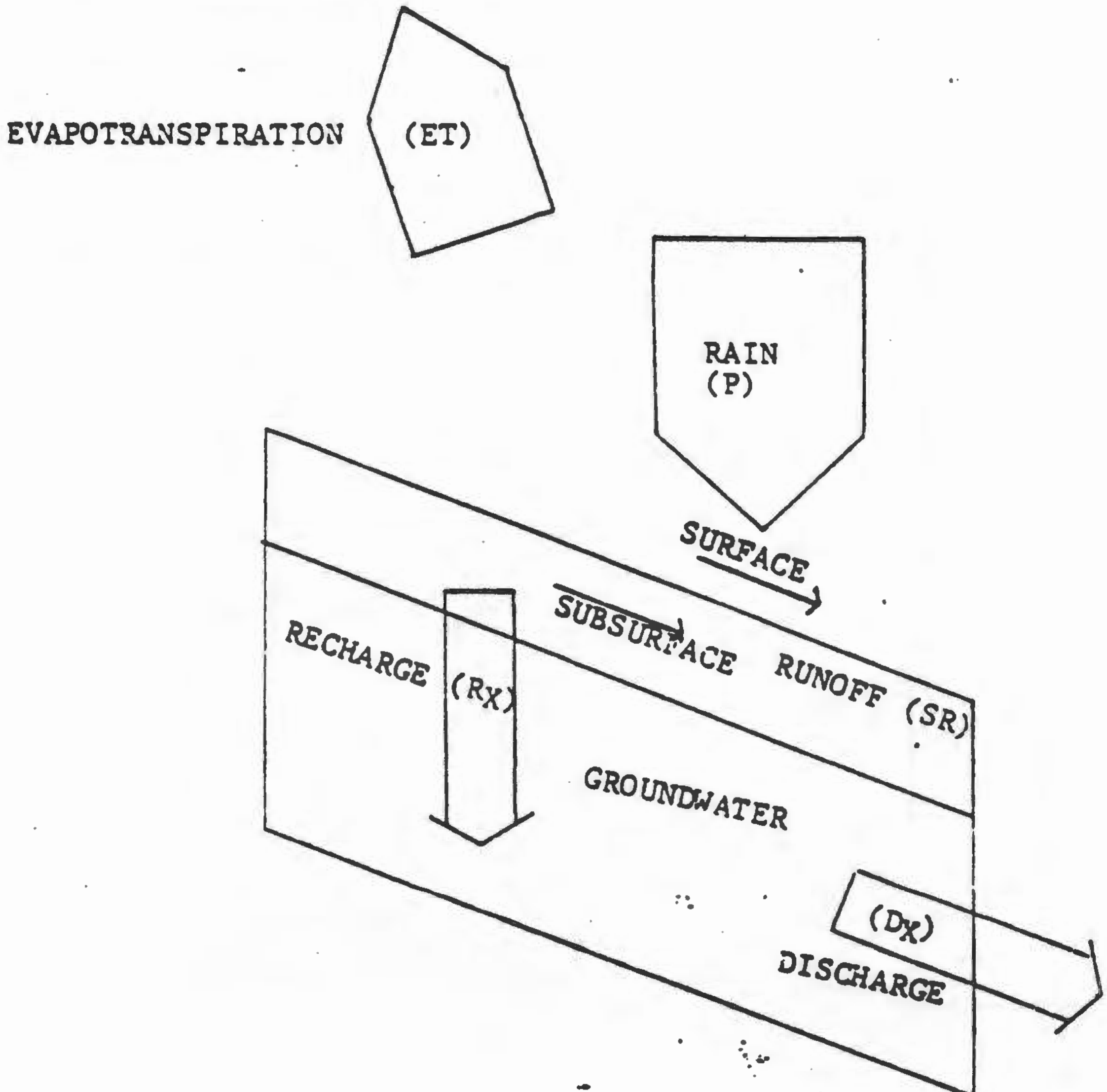


Figure 2. 643-G Flow Path Cross Section



$R_X = P - SR - ET \pm$ STORAGE CHANGE

$D_X = R_X$, IF STORAGE CHANGE $= 0$

Figure 3. Schematic Representation of Water Balance

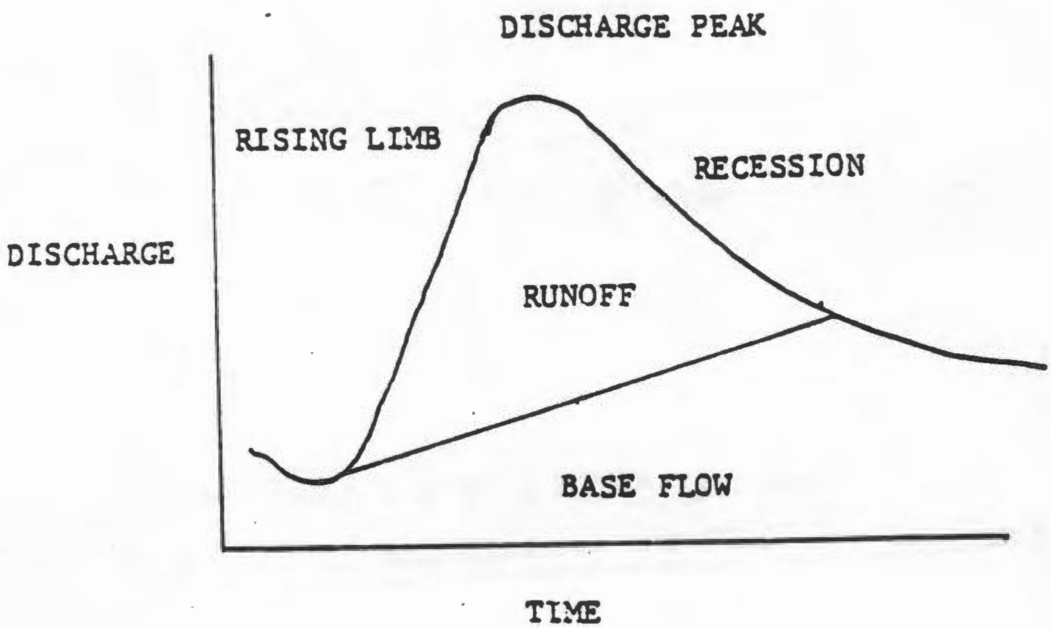
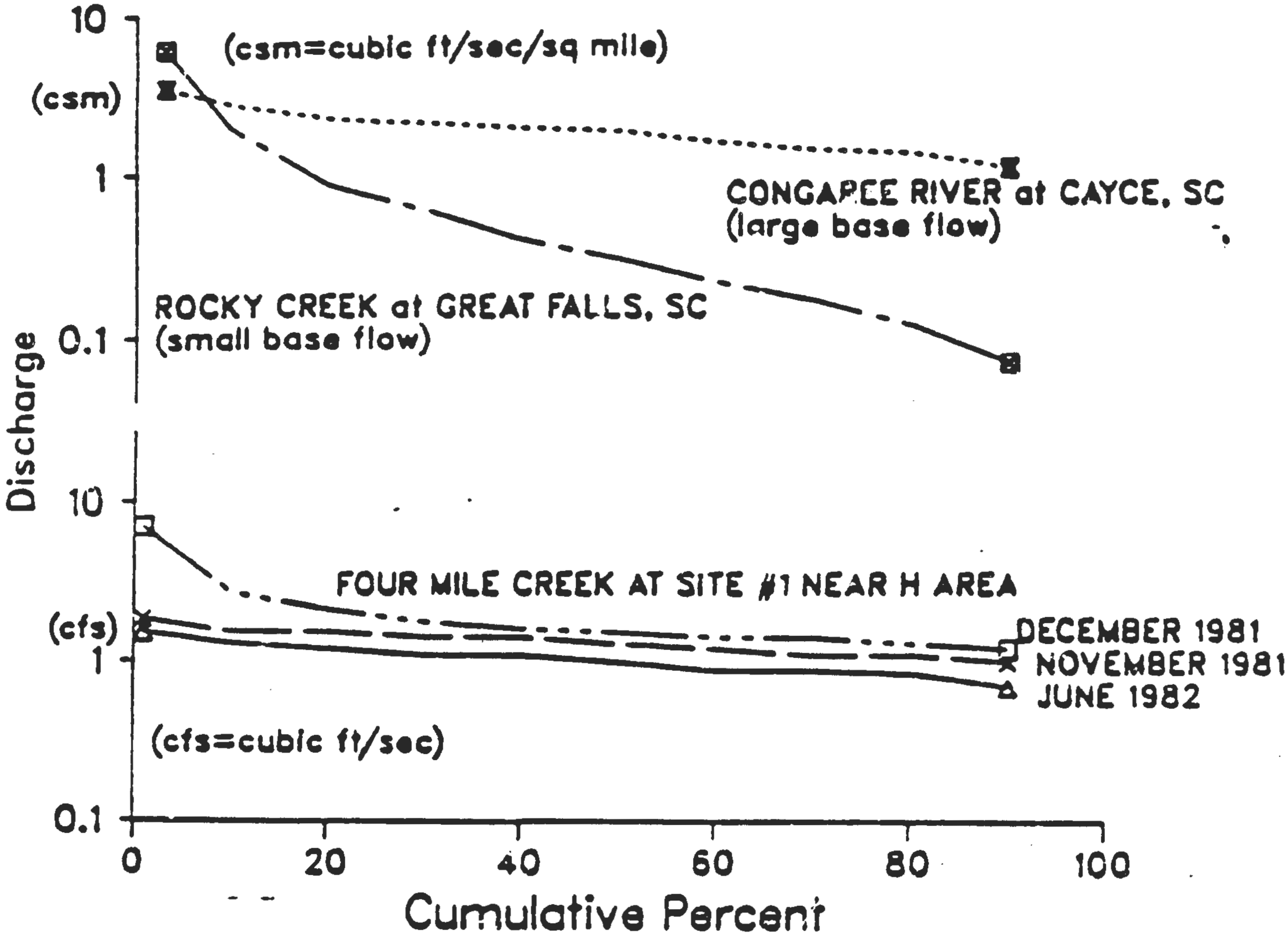


Figure 4. Simple Hydrograph of a Storm Event

Figure 5
Cumulative Flow Frequency Analysis



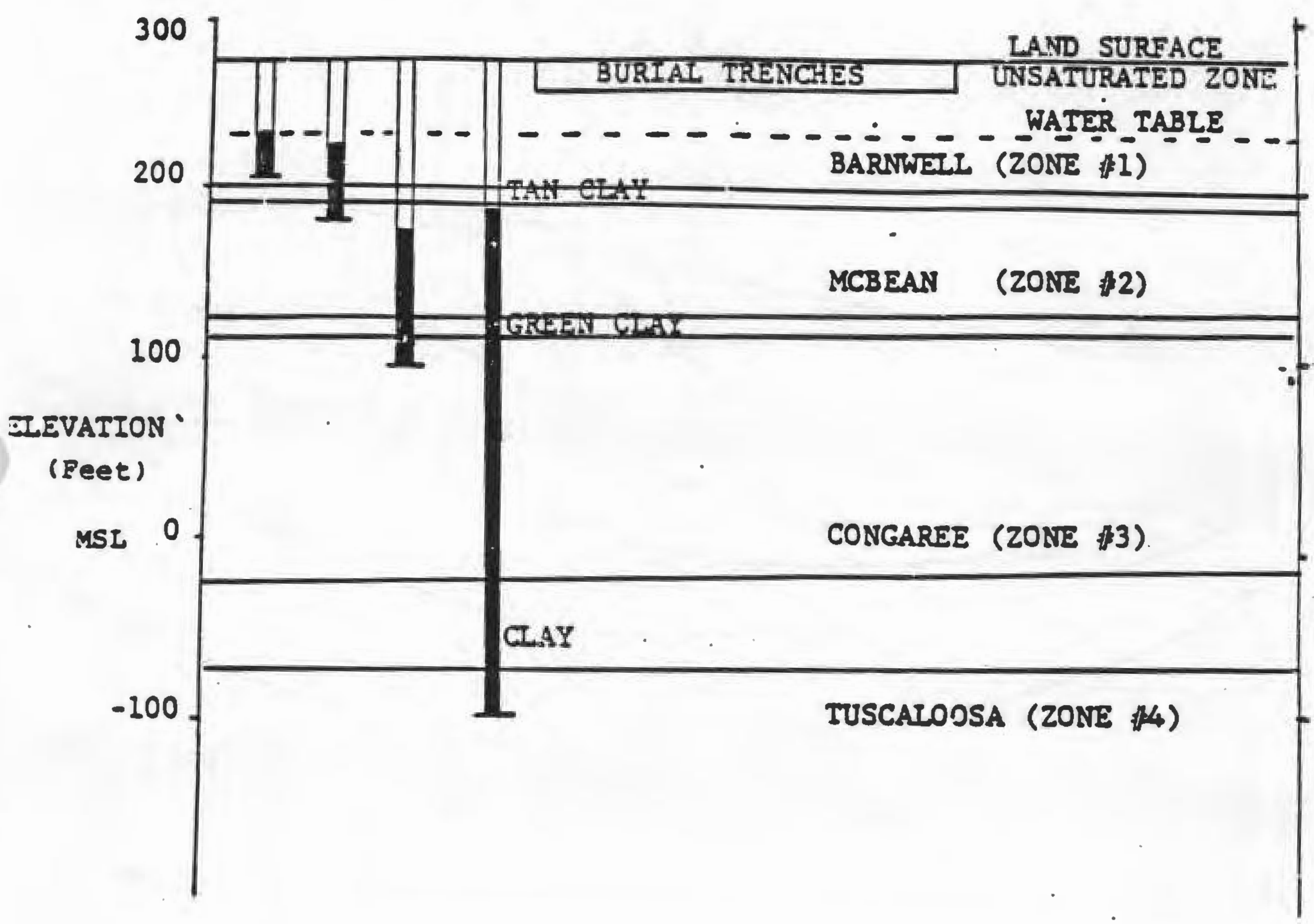


Figure 6.- Cross Section of Burial Ground Showing Groundwater Zones and Hydrostatic Head Relations

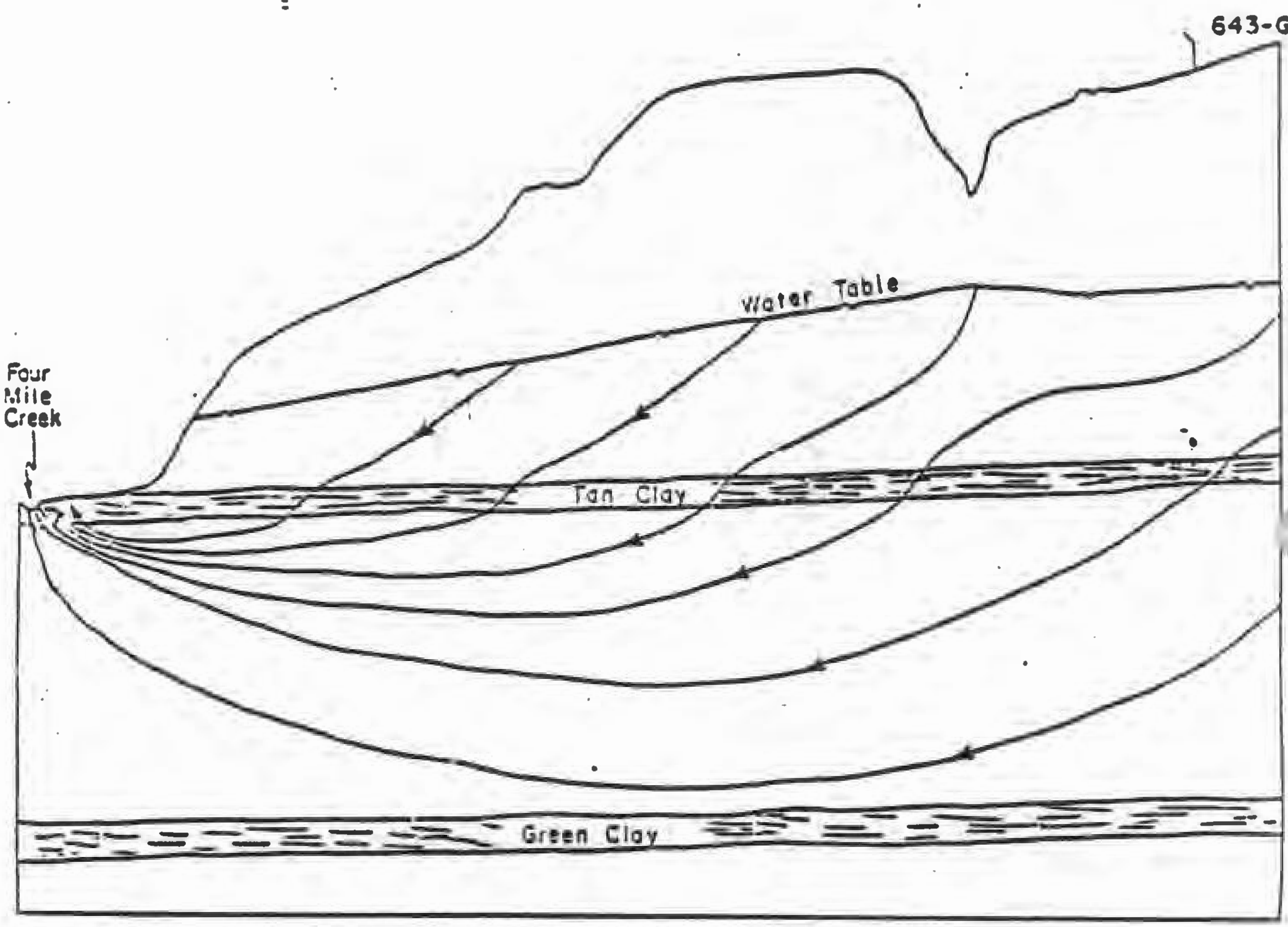


Figure 7. Possible Groundwater Flow Path in the Shallow Zones

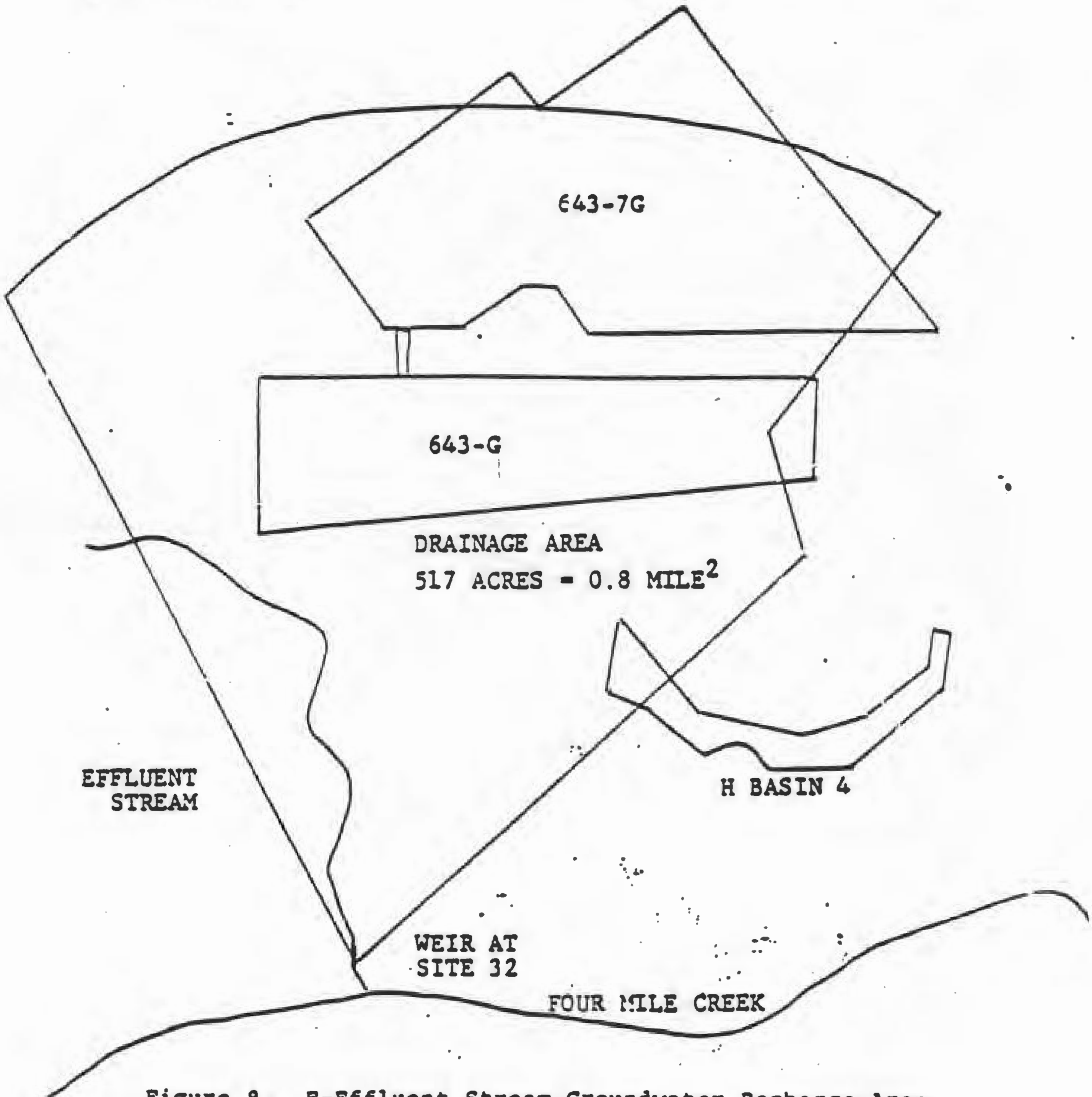


Figure 8. F-Effluent Stream Groundwater Recharge Area

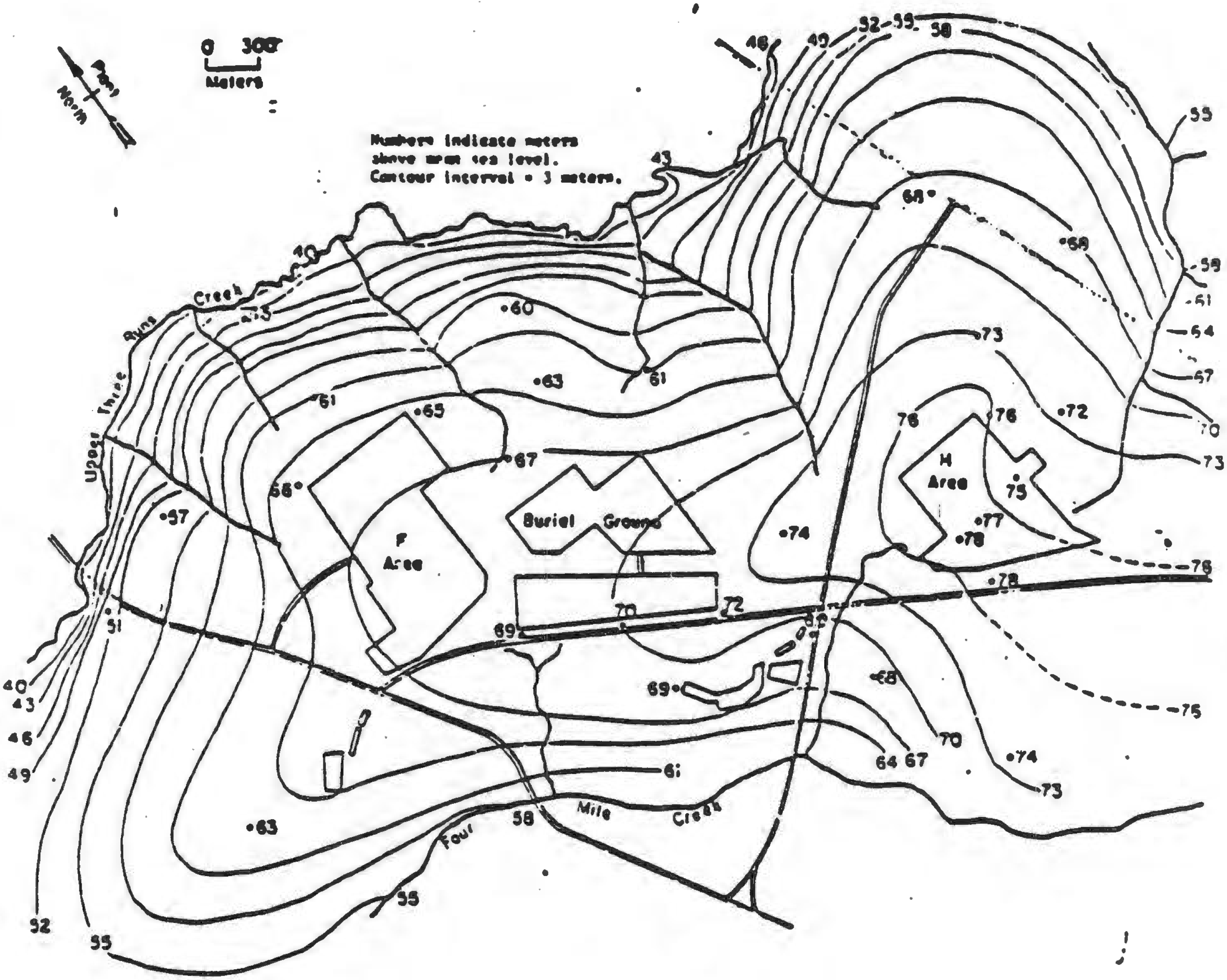


Figure _9. Elevation of the Hydraulic Head in the Upper Part of the McBean Formation (measured 8/29/77)

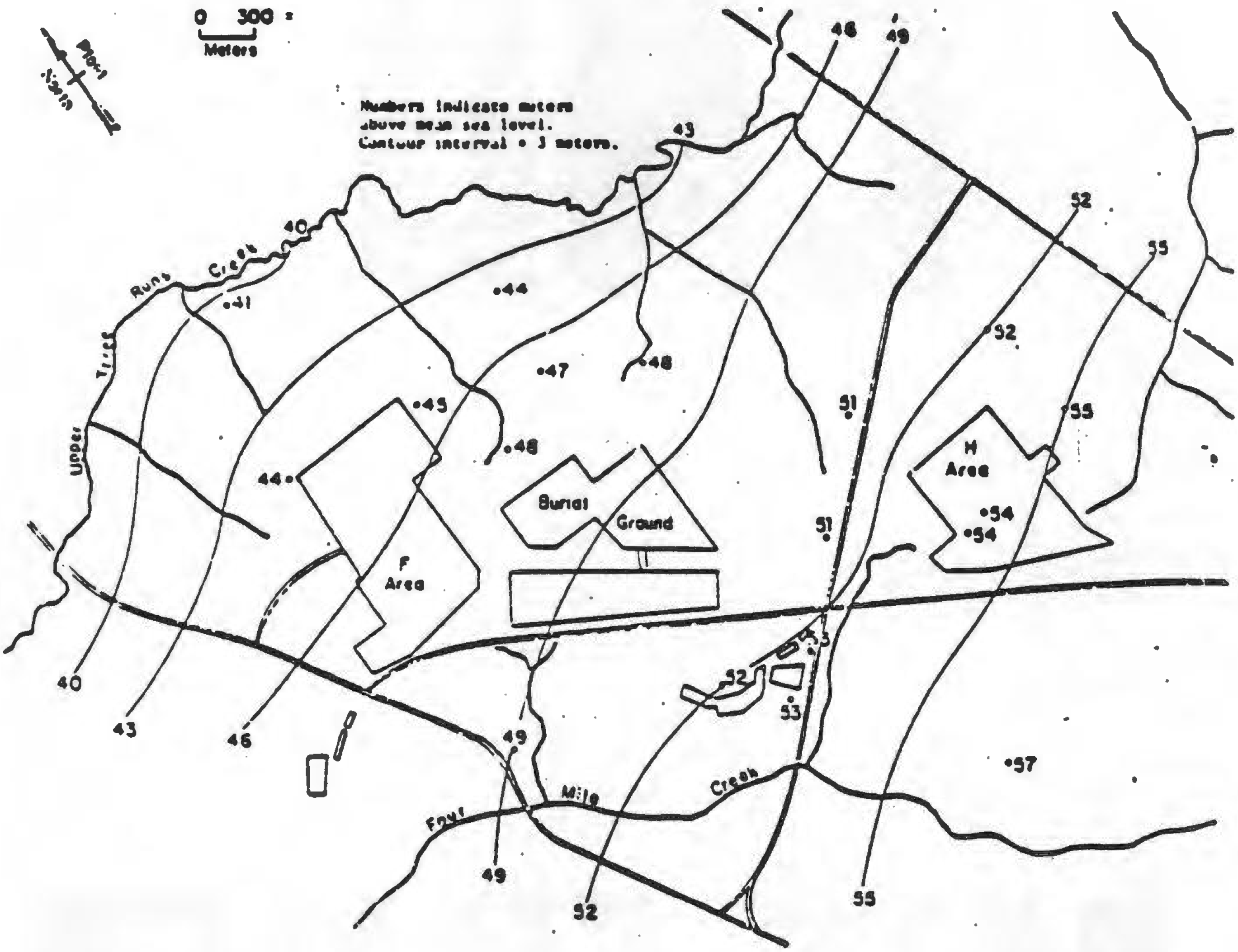


Figure 10. Elevation of the Hydraulic Head in the Upper Part of the Congaree Formation (measured 8/29/77)

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